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For: ECCENTRICITY COMPENSATION APPARATUS BASED ON FREQUENCY RESPONSE CHARACTERISTICS OF AN ACTUATOR OF A DISK DRIVE SERVO SYSTEM

SUBMISSION OF VERIFIED TRANSLATION OF PRIORITY DOCUMENT

Commissioner for Patents
PO Box 1450
Alexandria, VA 22313-1450

Sir:

Applicants submit herewith a translation of Korean Patent Application No. 2000-86283 claiming priority to December 29, 2000 and a statement from the translator.

If there are any fees associated with filing of this Submission, please charge the same to our Deposit Account No. 503333.

Respectfully submitted,

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Date: 12/21/05

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CERTIFICATION OF TRANSLATION

I, ***Young-ju Lee***, an employee of Y.P. LEE, MOCK & PARTNERS of The Cheonghwa Bldg., 1571-18 Seocho-dong, Seocho-gu, Seoul, Republic of Korea, hereby declare under penalty of perjury that I understand the Korean language and the English language; that I am fully capable of translating from Korean to English and vice versa; and that, to the best of my knowledge and belief, the statement in the English language in the attached translation of ***Korean Patent Application No. 10-2000-0086283*** consisting of 9 pages, have the same meanings as the statements in the Korean language in the original document, a copy of which I have examined.

Signed this 21th day of December 2005

Young-ju Lee

ABSTRACT

[Abstract of the Disclosure]

An eccentricity compensating apparatus of a disk drive servo system using the frequency response characteristics of an actuator for actuating a head to a position on a disk to read data on or reproduce data from the disk, the apparatus including: an error detector that detects a position error between a reference head position and an actual position of the head on the disk; a first compensation controller that receives the position error from the error detector and changes the actual position of the head in order to compensate for the position error; a second compensation controller that generates and outputs a control value to compensate for eccentricity which varies depending on the phase of a spindle that rotates the disk; and a gain/phase adjuster that adjusts the gain and phase of the control value output from the second compensation controller according to a disk reproduction speed, wherein a drive signal of the actuator is obtained by summing together signals output from the first compensation controller and the gain/phase adjuster. The eccentricity compensation apparatus can simply compensate for eccentricity at varying reproduction speeds by adjusting control data estimated for eccentricity compensation at specific reproduction speed based on the frequency response characteristics of an actuator.

[Representative Drawing]

FIG. 2

SPECIFICATION

[Title of the Invention]

Eccentricity Compensation Apparatus Based on Frequency Response Characteristics of Actuator of Disk Drive Servo System

[Brief Description of the Drawings]

FIG. 1 is a block diagram of a conventional disk drive servo system for compensating for eccentricity;

FIG. 2 is a block diagram of an eccentricity compensation apparatus using the frequency response characteristics of an actuator of a disk drive servo system according to the present invention; and

FIGS. 3(a) and 3(b) are graphs showing examples of the frequency response characteristics of an actuator.

[Detailed Description of the Invention]

[Object of the Invention]

[Technical Field of the Invention and Related Art prior to the Invention]

The present invention relates to eccentricity compensation in a disk drive servo system, and more particularly, to an eccentricity compensation apparatus of a disk drive servo system which can be effectively adapted to a variation in reproduction speed of a disk by adjusting the gain and phase of control data estimated at a specific reproduction speed and stored in a feedforward look-up table, based on the frequency response characteristics of an actuator.

Eccentricity occurs when the center of a disk track deviates from the axis of a spindle about which a disk rotates. The eccentricity acts as periodic disturbance on a disk drive system, thereby significantly degrading track following performance thereof. In particular, as speed at which a disk reproduction speed increases, eccentricity increasingly degrades the control performance of a disk drive system. Thus, in order to accurately trace a track at high reproduction speed, eccentricity needs to be effectively compensated for. A number of techniques have been developed to compensate for eccentricity.

FIG. 1 shows an example of a conventional disk drive servo system for compensating for eccentricity. Referring to FIG. 1, the conventional disk drive servo system includes an optical system 100, a feedback controller 110, a feedforward look-up table 120, and an actuator 130. The optical system 100 detects an error e(t) between the actual position of a head on a disk and a reference head position d(t), which corresponds to a displacement of the actuator 130, and outputs the error e(t) detected. The feedback controller 110 performs compensation control according to the error e(t) to output an actuator drive control value $U_{fb}(t)$. The feedforward look-up table 120 outputs an actuator drive control value $U_{ff}(t)$ which is estimated and stored according to the phase of a spindle in order to compensate for eccentricity. The actuator 130 is moved to a position on the disk by a control value U(t) which is obtained by the actuator derive control values $U_{fb}(t)$ and $U_{ff}(t)$, output from the feedback controller 110 and the feedforward look-up table 120, respectively.

The conventional disk drive servo system compensates for eccentricity by storing a compensation value for eccentricity compensation in the feedforward look-up table 120 and outputting the result of summation of the compensation value and the control value output from the feedback controller 110 as the actuator drive control value. Eccentricity varies depending on the phase of a spindle.

Eccentricity present in the disk drive servo system has constant magnitude and varying frequency as disk reproduction speed changes. The impact of eccentricity upon the

system due to changes in disk reproduction speed varies depending on the frequency response characteristics of the actuator 130. Thus, in order to effectively compensate for eccentricity, data of the feedforward look-up table 120 needs to be updated each time the disk reproduction speed changes. Since eccentricity becomes significantly larger at high reproduction speeds, the feedback controller 110 cannot appropriately perform a tracking control. In this case, data of the feedforward look-up table 120 cannot be updated, thereby making eccentricity compensation of the actuator 130 impossible.

[Technical Goal of the Invention]

To solve the above problems, it is an objective of the present invention to provide an eccentricity compensation apparatus of a disk drive servo system which can be effectively adapted to a variation in reproduction speed of a disk by adjusting the gain and phase of control data estimated at a specific reproduction speed and stored in a feedforward look-up table based on the frequency response characteristics of an actuator.

[Structure and Operation of the Invention]

Accordingly, to achieve the above objective, the present invention provides an eccentricity compensation apparatus of a disk drive servo system using the frequency response characteristics of an actuator for actuating a head to a position on a disk to read data on or reproduce data from the disk, the apparatus comprising: an error detector that detects a position error between a reference head position and an actual position of the head on the disk; a first compensation controller that receives the position error from the error detector and changes the actual position of the head in order to compensate for the position error; a second compensation controller that generates and outputs a control value to compensate for eccentricity which varies depending on the phase of a spindle that rotates the disk; and a gain/phase adjuster that adjusts the gain and phase of the control value output from the second compensation controller according to a disk reproduction speed, wherein a drive signal of the actuator is obtained by summing together signals output from the first compensation controller and the gain/phase adjuster.

It is preferable that the second compensation controller is a feedforward look-up table that stores control data estimated at a predetermined reproduction speed and to be used for eccentricity compensation through gain and phase adjustment.

It is preferable that the gain/phase adjuster adjusts the gain and phase of the control value output from the second compensation controller according to a reproduction speed based on the frequency response characteristics of the actuator.

Referring to FIG. 2, an eccentricity compensation apparatus using the frequency response characteristics of an actuator in a disk drive servo system according to the present invention includes an actuator 200, an error detector 210, a first compensation controller 220, a second compensation controller 230, and a gain/phase adjuster 240.

The actuator 200 determines the position of a head (a pickup head and the like) for recording data onto a disk or reproducing recorded data. Since the impact of eccentricity upon the system varies depending on disk reproduction speed, an appropriate compensation control for an error due to this eccentricity is needed in driving the actuator 200 to accurately follow a track. The error detector 210 detects an error e(t) (position error) between a reference head position d(t) and an actual position of the head on a disk. The first compensation controller 220 receives the position error e(t) from the error detector 210 and generates and outputs an actuator control value $U_{fb}(t)$ to compensate for the position error e(t) by changing the actual position of the head. The actuator control value $U_{fb}(t)$ output from the first compensation controller 220 is obtained by various possible control algorithms. The first compensation controller 220 serves as a feedback controller that receives a reference

signal and receives an actual signal of the actuator 200, which corresponds to the actual position of the head, and performs a compensation control using the received signals. The second compensation controller 230 receives and stores control values for one period to compensate for an error of the actuator 200 caused by periodic disturbances such as eccentricity of the disk at a specific reproduction speed. Here, the control values refer to estimated values of the phase and gain characteristics of the actuator 200 at the specific reproduction speed to be used for eccentricity compensation at varying reproduction speeds. The second compensation controller 230 serves as a feedforward look-up table for pre-storing estimated compensation values determined from simulations, tests, or experience by estimating the gain and phase characteristics of the actuator 200 upon eccentricity at a specific reproduction speed, before or upon a compensation control is performed. The gain/phase adjuster 240 adjusts the phase and gain of an output signal from the second compensation controller 230 according to varying reproduction speeds based on the frequency response characteristics of the actuator 200 and outputs an adjusted value $U_{ff}(t)$. The actuator 200 maintains a constant phase and gain for actuating even if the reproduction speed changes so long as the reproduction speed is less than a predetermined value. However, when the reproduction speed is a predetermined value or greater, the gain decreases and phase lag increases. That is, the control characteristics of the actuator 200 significantly change at a reproduction speed greater than the predetermined value. The gain/phase adjuster 240 calculates the adjusted value $U_{ff}(t)$ by changing the gain and phase of the output value of the second compensation controller 230 based on the frequency response characteristics of the actuator 200 which are dependent on reproduction speed variations. The actuator 200 is driven according to a drive signal obtained by summation of the actuator control value $U_{fb}(t)$ output from the first compensation controller 220 and the adjusted value $U_{ff}(t)$ output from the gain/phase adjuster 240.

In FIG. 3, (a) and (b) are graphical representations showing an example of frequency response characteristics of the actuator 200. Graphs (a) and (b) of FIG. 3 show changes in gain and phase with respect to frequency. Even when disk reproduction speed changes, identifying the frequency response characteristics of the actuator 200 enables the second compensation controller 230 to calculate the adjusted value $U_{ff}(t)$ from the estimated compensation values stored therein even if they have been estimated at a low speed reproduction, for eccentricity compensation at varying reproduction speeds.

The operation of the eccentricity compensation apparatus of FIG. 2 will now be described.

Compensating for eccentricity using a feedforward look-up table obtained based on the phase of a spindle is implemented in various ways. One approach is disclosed in Korean Patent Application No. 2000-0049866 (filed August 26, 2000) which describes eccentricity compensation using learning control techniques. At a specific reproduction speed at which a feedback controller corresponding to the first compensation controller 220 of FIG. 2 operates smoothly, control data in the feedforward look-up table for eccentricity compensation can be estimated in various ways using a tracking error signal. If control data of the feedforward look-up table for eccentricity compensation are accurately estimated, the magnitude of a tracking error is zero, and the feedforward look-up table can be obtained using Equation (1):

$$U_{ff}(s) = \frac{D(s)}{G(s)} \qquad \ldots (1)$$

Here, $U_{ff}(s)$, $D(s)$, and $G(s)$, which are the Laplace transforms for $U_{ff}(t)$, $d(t)$, and $g(t)$, denote the control data of the feedforward look-up table and eccentricity, respectively. The eccentricity $D(s)$ has constant magnitude and phase, while only the frequency varies as disk reproduction speed changes. The transfer function

G(s) of the actuator 200 expresses the frequency response characteristics of the actuator 200 in which the gain is decreased and the phase is lagged with increased frequency as shown in FIG. 3. If the data $U_{ff}(s)$ of the feedforward look-up table estimated at a specific disk reproduction speed using Equation (1) are applied to reproduction at a different speed (usually a higher reproduction speed) for the reason that the gain and phase of the actuator upon eccentricity are the same at any reproduction speed, compensation for eccentricity at the higher reproduction speed is incorrect. This is because actual gain reduction and phase lag caused by the frequency response characteristics of the actuator 200 at that reproduction speed are not reflected. Thus, the control data of the feedforward look-up table estimated at a specific reproduction speed cannot be applied in the same manner if there is a large change in reproduction speed. However, according to the present invention, the gain/phase adjuster 240 can compensate for gain reduction and phase lag in frequency response characteristics G(s) of the actuator caused by reproduction speed changes based on control data in a feedforward look-up table estimated at a specific reproduction speed, without updating the control data in the feedforward look-up table each time reproduction speed changes. That is, it is possible to use control data in the feedforward look-up table estimated at a low reproduction speed for a high-speed reproduction. In this case, the gain/phase adjuster 240 compensates for gain reduction and phase lag due to frequency changes at varying reproduction speeds, that is, frequency response characteristics, of the actuator 200.

[Effect of the Invention]

The eccentricity compensation apparatus according to the present invention can simply compensate for eccentricity at varying reproduction speeds by adjusting control data estimated for eccentricity compensation at specific reproduction speed based on the frequency response characteristics of an actuator.

What is claimed is:

1. An eccentricity compensation apparatus of a disk drive servo system using the frequency response characteristics of an actuator for actuating a head to a position on a disk to read data on or reproduce data from the disk, the apparatus comprising:

an error detector that detects a position error between a reference head position and an actual position of the head on the disk;

a first compensation controller that receives the position error from the error detector and changes the actual position of the head in order to compensate for the position error;

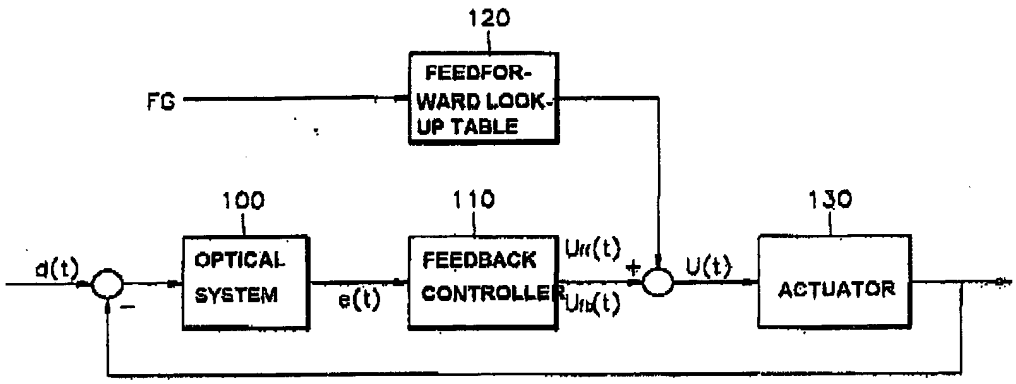
a second compensation controller that generates and outputs a control value to compensate for eccentricity which varies depending on the phase of a spindle that rotates the disk; and

a gain/phase adjuster that adjusts the gain and phase of the control value output from the second compensation controller according to a disk reproduction speed,

wherein a drive signal of the actuator is obtained by summing together signals output from the first compensation controller and the gain/phase adjuster.

2. The apparatus of claim 1; wherein the second compensation controller is a feedforward look-up table that stores gain/phase compensation values of the actuator, estimated at a predetermined reproduction speed.

3. The apparatus of claim 1, wherein the gain/phase adjuster compensates the control value output from the second compensation controller based on the frequency response characteristics of the actuator.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110
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d(t)
OPTICAL
SYSTEM
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FEEDBACK
CONTROLLER
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ACTUATOR
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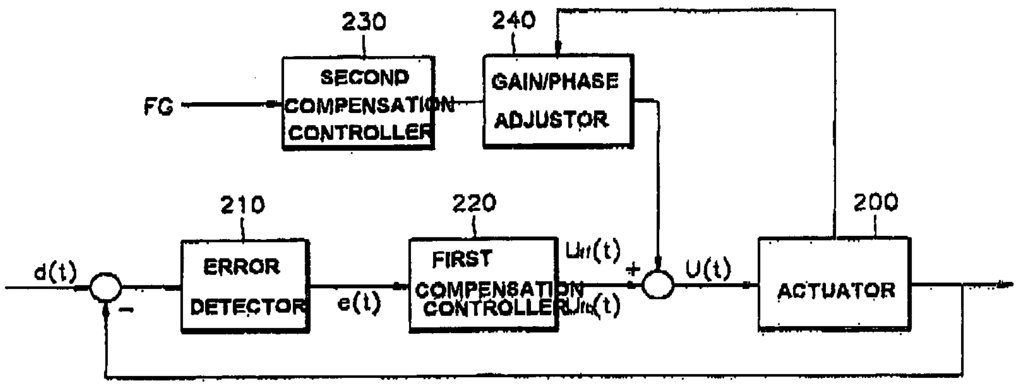
FIGURE 1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FG
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ACTUATOR
d(t)
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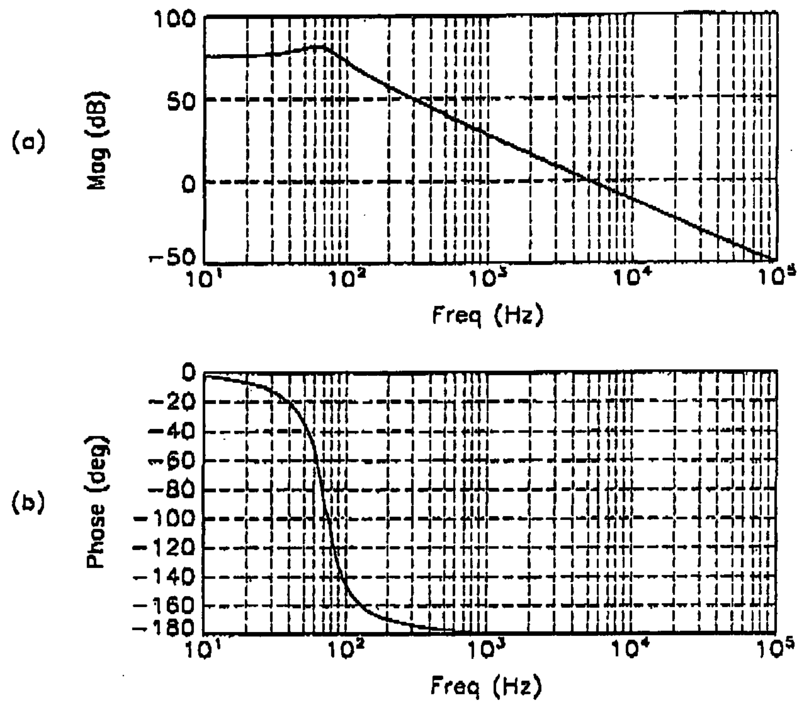
FIGURE 2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Freq (Hz)
(b)
Phase (deg)
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−100
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−140
−160
−180
10^1
10^2
10^3
10^4
10^5
Freq (Hz)

FIGURE 3